

5 FIELD OF THE INVENTION AND RELATED ART

Presently, there have been proposed various ink jet recording methods. Among those ink jet recording methods, the mainstream methods are those which record images by ejecting ink droplets by applying heat from exothermic resistors to the ink within a chamber in a recording head, in accordance with recording signals. As an example of such an ink jet recording method, there is the ink jet recording method disclosed in Laid-Open Japanese Patent No. 59,936/1979, according to which the phenomenon that application of thermal energy to ink generates bubbles in the ink, is used to eject ink. This type of ink jet recording method has become one of the mainstream methods in the present field of ink jet recording, because, according to this method, the openings (hereinafter, opening may be referred to as orifice)

It has been known that in a recording method which records images by ejecting ink from orifices by applying thermal energy to ink, in accordance with recording signals, with the use of exothermic resistors, the size of an ink droplet is dependent upon the apparatus conditions such as the amounts of thermal energy or pressure applied to ink, and physical properties, such as specific heat, thermal conductivity, thermal expansion constant, or viscosity, of ink. Thus, in order to consistently eject ink, many proposals have been made to control these factors. For example, Laid-Open Japanese Patent No. 132,253/1980 pays attention to a method for controlling the rising and falling of the voltage applied to a heat generating element, and also the fact that the temperature of an exothermic resistor changes in response to the changes in pulse width and pulse amplitude, and therefore, the bubble volume also changes in response to the changes in pulse width and pulse amplitude. Thus, it discloses an ink jet recording method which controls pulse width and pulse amplitude to eject ink consistently. The characteristics of a present day ink jet head definitely meet this technical standard. However, if substances which change in physical properties when

heated are contained in the ink, foreign substances (hereinafter, this may be referred to as burnt deposit) sometimes precipitate. If such foreign substances continue to precipitate by a large amount, they gradually precipitate on the surface of the protective film, which sometimes results in reduction in the efficiency with which heat is conducted to ink, and therefore, inconsistency in bubble generation. Consequently, bubbles necessary for ink ejection fail to be satisfactorily formed, and therefore, ink fails to be ejected by the amount necessary for normal recording, or ink is not ejected at all; in other words, there is a decline in the consistency with which ink is ejected. Also in recent years, a recording head has been drastically reduced in size, and also drastically improved in terms of operational precision, and with these improvements, the amount of ink ejected through a single ejection cycle has been decreasing. Consequently, the amount of energy which an exothermic resistor must apply to ink has also become smaller. In such an environment in which the amount of burnt deposit which adheres to the protective film is relatively small for the above described reason, the effects of the burnt deposit which adheres to the protective film, upon the ratio of the thermal energy prevented from being conducted from a heat generating element to ink, is rather

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large, sometimes causing changes in the amount by which ink is ejected, and therefore, derogatorily affecting the recording of highly precise images. Thus, it has become necessary to strictly control the generation of burnt deposit.

In the past, the above described precipitation of burnt ink ingredients has been dealt with by modifying ink in terms of ingredient.

It has been known that the burnt deposit contains both inorganic components such Fe and organic components.

As for the inorganic components, it is thought that the problem involving the inorganic components can be solved by adding chelating reagent to ink, because the addition of chelating reagent stabilizes ink by coordinating inorganic components. As for the organic components, it is thought that the problem involving the organic components can also be solved by the addition of chelating reagent to ink, because chelating reagent prevents organic components from crystallizing on the exothermic resistant layer. In other words, it is thought that the addition of chelating reagent to ink prevents carbonized deposit from accumulating on the exothermic resistant layer. Further, Laid-Open Japanese Patent Nos. 160,070/1991 and 80,664/1996 also disclose solutions to the problem regarding the burnt deposit. According to the former

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patent, oxonium anion is added to ink to control the precipitation of burnt ink ingredients, and according to the latter patent, phytic acid or phytate is added to ink to control the precipitation of burnt ink ingredients.

SUMMARY OF THE INVENTION

In the aforementioned ink jet head, the surface of the protective film, on the side which comes into contact with ink, is coated with an anti-cavitation film, which is mainly formed of tantalum (Ta). It has been known that not only is Ta highly resistant to mechanical shock, but also it is relatively corrosion resistant.

In consideration of the fact that the thinner the anti-cavitation film, the higher the efficiency with which heat is conducted from a heat generating element to ink, the anti-cavitation film is desired to be as thin as possible. In recent years, the number of heat generating elements in a recording head has been increased for high quality recording. Therefore, the thickness of the anti-cavitation film tends to be reduced to no more than 0.3 μm from the viewpoint of energy conservation. The provision of such a thin anti-cavitation film upon the exothermic resistant layer, and the usage of the above described ink, result in improvement in terms of the precipitation of

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burnt ingredients. However, it has also become evident that these measures created new problems. That is, the examination of Ta film after a continuous driving of an ink jet head revealed corrosion of the Ta film. It is thought that the corrosion of the anti-cavitation film formed of Ta occurs through two mechanisms. One mechanism is that cracks are generated at the crystal grain boundaries in the anti-cavity film, and the other mechanism is that Ta itself chemically reacts with the chelating reagent and the like contained in ink. In other words, if chelating reagent (for example, EDTA) is added to ink, that is, if the amount of chelating reagent is increased, the chelating reagent coordinates Ta, which is used as the material for the anti-cavitation film portion of the protective film, causing the protective film to corrode. This sometimes reduces the durability of an exothermic resistant layer. In particular, when a recording head is highly refined, the protective film is also highly refined, or highly reduced in thickness. Therefore, it is possible that even if the surface of the protective film in contact with ink is corroded only slightly, cracks occur in the protective film, and the cracks easily reach the exothermic resistant layer, and damage the exothermic resistant layer. For this reason, the amount of chelating reagent to be added to the ink must be adjusted.

Thus, even though the addition of chelating reagent seems to make some degree of improvement regarding the durability of a heat generating element and the problem of the burnt deposit, it does not seem to be
5 the fundamental solution to the above described problems.

Thus, the inventors of the present invention analyzed in detail the factors which caused the above described problems, that is, the precipitation of
10 burnt ink ingredients, inconsistency in ink ejection, and reduction in the durability of the heat generating element, and the like. As a result, it was discovered that there was a method for comprehensively solving these problems.

15 That is, in the past, it has been presumed that the above described problems are closely related to the physical properties of ink, driving conditions, and the like, and therefore, there were no simple solutions to them. However, the studies made by the
20 inventors of the present invention regarding the causes of the precipitation of burnt ink ingredients and the destruction of the heat generating element while paying attention to the surface on which the burnt ink ingredients precipitate revealed that the
25 amount by which the burnt deposit was generated was dependent upon the highest temperature to which the surface of the protective film in contact with ink

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temperature of the aforementioned protective layer surface no higher than 560°C, the thicknesses and thermal conductivities of the various layers of the protective film, and the voltage and width of the pulses applied to drive the exothermic resistant layer, had to be controlled; in particular, when the protective film was very thin and was excellent in thermal conductivity, controlling the width and voltage of the driving pulses was one of the essential solutions to the above described problems. Thus, the inventors of the present invention created a mathematical model based on the structure of an actual heat generating head, and simulated printing operations, in which the highest temperatures which the aforementioned surface reached were precisely obtained while varying the driving pulses. As a result, the present invention was completed, which could provide an ink jet head base board, an ink jet head, and an ink jet recording method, which could assure that the aforementioned highest temperature would be kept no higher than 560°C.

As described above, the primary object of the present invention is to provide an ink jet head base board, an ink jet head, and an ink jet recording method, which comprehensively solve the aforementioned problems: the precipitation of burnt ink ingredients, inconsistency in ejection, and shortening of the

length of the durability of a heat generating element.

According to an aspect of the present invention, there is provided an ink jet recording method of ejecting ink using an ink jet head substrate
5 provided with a heat generating resistor which is coated with a protecting film, wherein the ink is ejected by a pressure produced by generation of a bubble created by film boiling of the ink caused by application of thermal energy to the ink through the
10 protecting film, the thermal energy being generated by driving of said heat generating resistor, the improvement residing in that there is provided a recording mode in which the ink is ejected with a maximum temperature at the surface of said protecting
15 film which is contacted to the ink not higher than 560°C.

According to another aspect of the present invention, there is provided an ink jet head comprising an ink jet head substrate including a heat
20 generating resistor, a protecting film with which said heat generating resistor is coated, wherein heat generated by said heat generating resistor is applied to ink through said protecting film to create a bubble in the ink, thereby to eject the ink by a pressure by
25 the creation of the bubble, the improvement residing in that a maximum temperature at a surface of said protecting film contacted to the ink is not higher

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than 560°C during driving of said heat generating resistor.

According to a further aspect of the present invention, there is provided an ink jet apparatus
5 which includes an ink jet head comprising an ink jet head substrate including a heat generating resistor, a protecting film with which said heat generating resistor is coated, wherein heat generated by said heat generating resistor is applied to ink through
10 said protecting film to create a bubble in the ink, thereby to eject the ink by a pressure by the creation of the bubble, the improvement residing in that there is provided driving signal control means for making a maximum temperature at a surface of said protecting
15 film contacted to the ink not higher than 560°C during driving of said heat generating resistor.

According to the present invention, the highest temperature which the protective film surface is allowed to reach is set at a temperature no higher
20 than 560°C, not only are the ink ingredients prevented from precipitating, as burnt deposit, on the surface (heat transmission surface) of a heat generating element, but also the protective film is prevented from being shaved away. Therefore, even when the
25 exothermic resistant layer is further reduced in thickness and size, and therefore, the amount of the thermal energy generated by the exothermic resistant

layer becomes smaller, the problem that the thermal energy is prevented from being efficiently transmitted, by the accumulation of burnt ink ingredients, can be controlled to make it possible to
5 form highly precise images of high quality, as well as to provide an ink jet head base board and ink jet head, which are superior in ejection consistency and durability.

With the application of the present
10 invention, even when chelating reagent was added to ink, the precipitation of burnt ink ingredients could be controlled and the corrosion of the protective film could be prevented, as long as the highest temperature of the surface of the protective film in contact with
15 ink kept no higher than 560°C.

Incidentally, when adding chelating reagent to ink, if the amount of the chelating reagent added to ink is greater than a certain value, the chelating reagent sometimes settles because of the solubility of
20 the chelating reagent, whereas if it is smaller than a certain value, the chelating reagent does not show its effects. Thus, the amount of the chelating reagent is desired to be no less than 50 ppm in weight and no more than 20 wt.%, preferably, no less than 80 ppm in
25 weight and no more than 10 wt.%, relative to the entirety of the ink.

The degree of protection offered to anti-

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cavitation film against corrosion by the present invention is far greater compared to that offered by the conventional methods. However, in order to further improve the corrosion protection for the protective film, that is, in order to protect the protective film from a larger variety of inks, the aforementioned layer of the protective film which makes contact with ink, that is, the anti-cavitation film, may be formed of amorphous alloy containing Ta. Further, the amorphous alloy for the anti-cavitation film may contain no less than one material among Fe, Cr, and Ni, in addition to Ta. Incidentally, the aforementioned amorphous alloy was composed of Ta, Fe, Cr, and Ni, and when the amount of Ta relative to the entirety of the amorphous alloy was no more than 30% in weight, the amorphous alloy was more effective.

There are no crystal grain boundaries in the anti-cavitation film formed of this amorphous alloy containing Ta. Therefore, the anti-cavitation film does not sustain the cracks which might otherwise occur. Further, the surface of the amorphous alloy containing Ta becomes passive by being oxidized, and this passive state prevents the anti-cavitation film from reacting with ink ingredients. For these reasons given above, anti-cavitation film formed of amorphous alloy containing Ta has more resistance to the corrosion caused by ink, compared to the conventional

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anti-cavitation film. According to the present invention, the highest temperature of the surface of the protective film in contact with ink is kept no higher than 560°C, which alone is effective to keep
5 the corrosion of the anti-cavitation film under control. However, according to the present invention, an additional measure is taken, that is, the anti-cavitation film is formed of amorphous alloy containing Ta, and therefore, the corrosion of the
10 anti-cavitation film is better controlled because of the synergistic effects of the lower temperature and usage of amorphous alloy containing Ta.

The amorphous alloy as the material for the anti-cavitation film may be produced using no less
15 than one kind of metal among Fe, Cr, Re, Ge, and Ni, in addition to Ta. Further, using four kinds of metallic materials, that is, Ta, Fe, Cr, and Ni as the materials for the anti-cavitation film, in such a ratio that Ta occupies no more than 30% in weight of
20 the entirety of the finished alloy, improves the Ta containing alloy in terms of the above described beneficial characteristic, making it possible to better control the corrosion of the anti-cavitation film, and also to extend the service life of a heat
25 generating element.

In other words, it becomes possible to extend the length of the service life of a recording head to

a degree that it virtually matches that of an ink jet recording apparatus, eliminating the need for recording head replacement.

These and other objects, features, and advantages of the present invention will become more apparent upon consideration of the following description of the preferred embodiments of the present invention, taken in conjunction with the accompanying drawings.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a plan view of the circuit configuration of the base board of a recording head in accordance with the present invention.

15 Figure 2 is a sectional view of the circuit elements of a recording head in accordance with the present invention.

Figure 3 is a plan view of the circuit elements of a recording head in accordance with the present invention.

20 Figure 4 is a sectional view of a heat generating head in accordance with the present invention.

Figure 5 is a schematic perspective view of a recording head with multiple heat generating heads, and depicts the general structure thereof.

Figure 6 is a schematic perspective view of

an embodiment an ink jet recording apparatus in accordance with the present invention.

Figure 7 is a vertical sectional view of an embodiment of an ink cartridge in accordance with the present invention.

Figure 8 is a schematic perspective view of an embodiment of a recording unit in accordance with the present invention.

Figure 9 is a schematic perspective view of a recording head having four ink cartridges.

Figure 10 is a schematic perspective view of a heat generating head and four ink cartridges arranged on the head.

Figure 11 is a sectional view of an example of a heat generating head in accordance with the present invention.

Figure 12 is a schematic perspective view of a recording head in accordance with the present invention.

Figure 13 is a schematic view of an ink jet recording apparatus in accordance with the present invention.

Figure 14 is a graph which shows the relationship between the ratio of the remaining portion of the anti-cavitation film and the highest temperature which the temperature of the surface of the anti-cavitation film reached.

Figure 15 is a graph which shows the head driving pulse for modulating the ejection amount in one of the embodiments of the present invention.

Figure 16 is a graph which shows the relationship between the width of the driving pulse shown in Figure 15, and the amount of the ejected ink.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, the preferable embodiments of the present invention will be described in more detail. The embodiments of the present invention are not limited to those which will be described hereinafter. The application of the present invention to an ink jet recording method in a manner represented by the following embodiments of the present invention enhances the already superior characteristics of the ink jet recording method.

(Upper Limit of Temperature)

First, the highest temperature reached by the interface between the protective film and ink during the printing operation simulation carried out for the completion of the present invention will be described. The amount P of the thermal energy released by the exothermic resistant layer per unit of time satisfies the following mathematical formula:

$$P = V^2 / (R + r) \times P_w \times N \quad \dots(1)$$

V: driving voltage [V]

r: resistance of wiring electrically connected to exothermic resistant layer [Ω]

N: total number of sub-layers in the exothermic resistant layer.

$$R = \rho_s \times LH/WH \quad \dots (2)$$

ρ_s : resistance value of exothermic resistant layer

[Ω/\square]

LH: length of exothermic resistant layer [μm]

15 WH: width of exothermic resistant layer [μm]

The maximum value W of electrical power consumed by the exothermic resistant layer per unit area and per unit time can be expressed in the form of:

$$20 \quad W = P/LH/WH \quad \dots (3)$$

The amount of the thermal energy generated in the exothermic resistant layer can be adjusted based on the actual size of the exothermic resistant layer, and the relationship among the above formulas (1) - (3).

Further, the temperature T at the interface between the surface of the protective film and ink

while thermal energy is generated can be obtained by solving a linear equation (4) using difference calculus.

$$\rho C(\partial T/\partial t) = k(x)(\partial^2 T/\partial x^2) + P \quad \dots(4)$$

- 5 ρ : average density of protective film [kg/m^3]
 C : average specific heat capacity [$\text{J}/(\text{kg}\cdot\text{C})$]
 $K(x)$: thermal conductivity of protective film at
point x [$\text{W}/(\mu\text{m}\cdot\text{C})$]
 t : time (μsec)
10 x : distance from referential point ($x = 0$), or
position of bottom surface of protective film, in
direction in which sub-layers of protective film are
accumulated [μm]
 P : thermal energy [W]

- 15 The change in the temperature T was simulated
by numerically solving Equation (4) under a
predetermined initial condition. As a result, it was
discovered that the temperature T could be kept no
higher than 560°C by thinning the protective film in
20 order to shorten the heat conduction time, or by
narrowing the driving pulse width in Equation (1), for
example.

- These methods can be carried out
independently, in combination, or in combination with
25 additional parameters (for example, driving voltage).

 However, thinning the protective film beyond
a certain thickness is not desired, because it reduces

Further, the inventors of the present invention discovered that under a condition that the driving voltage was within a range from a voltage level equal to the threshold voltage for causing ink to boil, to a voltage one and a quarter times the threshold voltage, a sufficient amount of thermal energy could be supplied, while keeping the temperature T no higher than 560°C, by making the width of the driving pulse no more than 5 μ sec, preferably, no more than 3 μ sec.

The recording head in this embodiment comprises: a plurality of heat generating heads; a plurality of ink paths connected one for one to the heat generating heads, and a single or plurality of ink chambers for supplying ink paths with ink. Each heat generating head comprises: an exothermic resistant layer formed on a piece of substrate, a driver for driving the exothermic resistant layer areas one for one, and the protective film. The

recording head also comprises a recording head base board, which comprises: a plurality of orifices through which ink is ejected; an ink ejecting portion having a plurality of ink paths inclusive of the heat
5 generating heads, that is, the areas where thermal energy acts on ink; and a plurality of the areas of exothermic resistant layer as means for generating thermal energy.

As for the recording head circuit, various
10 circuits have been developed. Some of the recording head circuits are formed on a single piece of substrate, and integrally comprise: a plurality of exothermic resistant layer areas aligned in a predetermined manner; a plurality of drivers provided
15 one for one for the plurality of exothermic resistant layer areas in order to drive them according to image formation data; a shift register, the bit count of which equals the number of the exothermic resistant layer areas, and which parallelly outputs the serially
20 inputted image formation data to the plurality of drivers; and a latching circuit for temporarily storing the data outputted from the shift resistor.

Figure 1 illustrates a recording head circuit such as the one described above, on the recording head
25 substrate. In Figure 1, a referential numeral 101 designates each of the exothermic resistant layer areas aligned in a straight line. A referential

numeral 102 stands for each of the power transistors,
and a referential numeral 103 stands for a latch
circuit. A referential numeral 104 stands for a shift
resistor, and a referential numeral 105 stands for a
5 clock for activating the shift resistor 104.
Referential numerals 106 and 107 designate an image
formation data input portion, and a heat pulse width
input portion for externally controlling the ON-time
of the power transistor, respectively. Referential
10 numerals 108 and 109 stand for a logic power source
and a GND, respectively. Referential numerals 110 and
111 designate an exothermic resistant layer driving
power source (VH), and a power transistor (Vce),
respectively.

15 In a printing apparatus having a head
containing a recording head circuit structured as
described above, the image formation data are serially
inputted to the shift register 104 from the image
formation data input portion 106. The inputted data
20 are temporarily stored in the latch circuit 103, and
while they are temporarily stored, pulses are inputted
from the heat pulse width input portion 107. As the
pulses are inputted, the power transistors 102 are
turned on, the exothermic resistant layer areas 101
25 are driven, the ink within the liquid paths connected
to the driven exothermic resistant layer areas 101 is
heated and ejected through the ejection orifices; in

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other words, a print is produced.

The employment of a circuit structured as described above makes it possible to substantially reduce the driving pulse width, which in turn makes it possible to raise the driving voltage V while keeping the temperature T no higher than 560°C, so that the thermal energy applied to ink is kept constant. As a result, ink can be consistently ejected. Next, an example of an element in which the above described circuit has been realized will be described with reference to Figures 2 and 3.

Figure 2 is a sectional view of an example of an element in which the circuit illustrated in Figure 1 has been realized. A referential numeral 201 designates a P-type silicon substrate; 202, an embedded N-type collector; 203, an embedded P-type element isolator region; 204, an N-type epitaxial region; 205, P-type base region; 206, an embedded P-type element region; 207, an embedded N-type collector region; 208, a high density P-type base region, 209, a high density P-type element isolation region; 210, an N-type emitter region; 211, an N-type collector region; 212, a collector electrode; 213, a base electrode; and a referential numeral 214 designates an emitter electrode.

Figure 3 is a plan view of an example of an element in which the circuit illustrated in Figure 1

has been realized. A referential numeral 301 stands for a piece of electrically insulative substrate. One of the edge portions of the substrate 301 is provided with a plurality of exothermic resistant layer areas 302, which are parallelly aligned along the edge. Each exothermic resistor area 302 is placed in a liquid path, adjacent to the end, or the outlet, of the liquid path. Placed in the approximate center portion of the substrate 301 are power transistors 303, as the transistors for driving the exothermic resistant layer areas 302 one for one, which are placed in such a manner that their longer edges become parallel to each other, and their shorter edges become aligned in the direction perpendicular to the longer edges of the exothermic resistant layer areas 302. In this embodiment, the power transistors 303 are bipolar transistors, and are characterized in that they are aligned in a single layer and in a straight line, in such a manner that their longer edges become parallel to each other, and their shorter edges become aligned in the direction perpendicular to the longer edges of the exothermic resistant layer areas 302. In order to drive the exothermic resistant layer areas, the same number of power transistors as that of the exothermic resistant layer areas 302 are necessary; each exothermic resistant layer area needs one power transistor. In another edge portion of the substrate

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301, that is, the edge portion on the side opposite to where the exothermic resistant layer areas 302 are arranged, an S/R circuit 309 comprising a shift register and a latch portion is placed, along with a plurality of input signal pads for the S/R circuits 309, in the adjacencies of the cluster of the aforementioned power transistors 303, the signal pads being on the edge side. A referential numeral 311 stands for a +VII common wiring for applying a predetermined voltage to the exothermic resistant layer areas 302, and a referential numeral 312 stands for a GND. At both longitudinal ends of the cluster of the power transistors 303 in terms of the direction in which the power transistors 303 are parallelly aligned, a heater 313 for temperature adjustment is provided, and in the adjacencies of one of the heaters 313, a sub-heater 314 is provided. Further, a pair of temperature sensing diodes 315 are placed in the corner portions the substrate 301, corresponding to both longitudinal ends of the aforementioned cluster of exothermic resistant layer areas 302, one for one.

In this embodiment, these temperature sensors read the temperature of the substrate, and the data obtained by the temperature sensors are sent to a RAM (unillustrated) disposed within the ink jet recording apparatus. After being sent to the RAM (unillustrated) in the ink jet recording apparatus,

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$$T_{real} = T_{base} + T_{temp} \quad \dots (5)$$

wherein Temp is obtained as T in Equation (4) given above.

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As the number of the substrate temperature data (Base) sent from the temperature sensor diodes once for every predetermined length of time reduces to a level at which Treal is no higher than 560°C, the data transmission is restarted. Incidentally, in the case of a printer, such as a serial printer, which forms an image line by line, even if Emerg is issued, the data transmission is not stopped until the line being printed is completed.

In such a case, the surface temperature of the heater sometimes exceeds 560°C, but such incidents have been known to have no significant effect upon the overall service life.

The substrate 301 is provided with four through holes 316 and two through holes 317. The four through holes 316 are located one for one at the four corners of the cluster of the second power transistors 303, and the two through holes 317 are located adjacent to the aforementioned diodes 315, one for one. These through holes 316 and 317 are provided for making contact with two wiring layers disposed below. Disposed one for one at the longitudinal ends of the cluster of the second power transistors 303 in terms of the alignment direction of the power transistors 303 are a pair of marks 318 used for position detection during assembly.

Figure 4 offers a schematic sectional view of

an example of a recording head equipped with heat generating heads in accordance with the present invention, at the vertical plane which divides one of the orifices into equal longitudinal halves. It also
5 offers a sectional view thereof, at a plane A-B in the first schematic sectional view. A recording head 13 is formed by bonding a glass, ceramic, or plastic plate having a plurality of grooves 14 for forming ink paths, to a heat generating head 15. The heat
10 generating head 15 comprises a plurality of layers of films: an anti-cavitation film layer 16-1 formed of amorphous alloy containing Ta; a protective film layer 16-2 formed of silicon oxide or silicon nitride; an aluminum electrode layer containing electrodes 17-1
15 and 17-2, a heat generating film layer 18 formed of TaN or the like, a heat storage film layer 19, and supporting layer 20 formed of alumina or the like superior in heat radiation, which are listed in order from the side which makes contact with the ink. The
20 protective film layer comprises two sub-layers: the anti-cavitation film layer 16-1 and the protective layer 16-2. In order to assure that a sufficient amount of thermal energy was supplied to the ink while keeping the temperature of the surface of the anti-
25 cavitation film 16-1 and the ink no higher than 560°C, and also in order to assure the durability, the overall thickness of the protective film was made to

5 Ta18Fe57Ni8Cr17.

Ink 21 reaches as far as the ejection orifices 22, forming a meniscus 23 with a predetermined amount of pressure. As an electrical signal is applied to the aluminum electrode 17, a region n of the heat generating head 15 suddenly generates heat, and the portion of the ink 21 in contact with the region n boils, that is, generates a bubble. As a result, the meniscus 23 is caused to protrude outward by the pressure from the bubble. Eventually, a certain amount of ink 21 is ejected in the form of an ink droplet 24 by the pressure from the bubble, from the orifice toward a piece of recording medium 25, for example, a sheet of paper. The ejected ink droplet 24 flies to the recording medium 25 and adheres to the image formation area of the recording medium 25, to form a microscopic section of an image.

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(Driving of Recording Head)

Figure 15 is a graph which depicts a split pulse for driving a recording head. In this drawing, VOP stands for the driving voltage level; P1, the pulse width of the first portion (hereinafter, "pre-heat pulse") of the heat pulse split in two portions; P2, an interval time; and P3 stands for the pulse width of the second portion of the pulse (hereinafter, "main heat pulse"). T1, T2, and T3 represent points of time which correspond to the widths P1, P2, and P3.

The interval time is provided as an interval for preventing the pre-heat pulse and main heat pulse from interfering with each other, and also for making uniform the temperature distribution throughout the ink within the ink path. The main heat pulse is for generating bubbles so that ink is ejected from the

5 In the recording head in this embodiment, if the pre-heat pulse width P1 is varied within a given range under a condition in which the driving voltage VOP is X (V) ($VOP = X$), and the main heat pulse width P3 is Y (μsec) ($P3 = Y$), there is a relationship as

10 shown in Figure 16 between the amount Vd by which ink is ejected, and the pre-heat pulse width P.

Figure 16 is a graph which shows that the amount by which ink is ejected is dependent upon the pre-heat pulse. In the graph, V_0 stands for the amount of ink ejected when $P_1 = 0$ (μsec). As is indicated by a curved line a in Figure 16, the amount V_d by which ink is ejected linearly increases within a pulse width P_1 range of zero to $P_{1\text{LMT}}$. However, as the pulse width P_1 is increased beyond $P_{1\text{LMT}}$, the amount V_d by which ink is ejected reaches its maximum when the pulse width P_1 is $P_{1\text{MAX}}$.

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In the pulse width P1 range in which P1 is greater than P1MAX, the amount Vd by which ink is ejected is smaller than VMAX. This is for the

Defining the inclination of the straight line representing the relationship between the ejection amount and pulse width within the pulse width range in which $P1 = 0 \sim P1_{LMT}$ (μsec) as the coefficient of pre-heat pulse dependency, there is the following relationship: coefficient of pre-heat pulse dependency (KP) = $(\Delta VdP)/(\Delta P1)$ [$\text{ng}/\mu\text{sec} \cdot \text{dot}$]. This coefficient KP is not dependent upon temperature, and instead is dependent upon head structure, driving condition, ink properties, and the like. The curved lines b and c in

In this embodiment, the condition in which a recording head in accordance with the present invention is driven in the normal printing mode is that pre-heat pulse $P1 = Pa$ (μsec), with which the ejection amount Vd becomes Va when driving voltage $VOP = X$ (V), and main heat pulse width $P3 = Y$ (μsec). Under this driving condition, the highest temperature of the recording head does not reach 560°C while ink is ejected.

In the above described case, the pulse width modulation driving control using double split pulse was employed. However, a multi-split pulse such as a triple split pulse or a pulse with a larger number of splits may be employed. Further, a pulse width modulation driving method in which a non-split pulse is employed and the main pulse width is modulated may be employed. In other words, any pulse width modulation driving method may be employed as long as the highest temperature which the recording head reaches can be kept no higher than 560°C.

In the case of a special printing mode, for
25 example, when large recording dots are necessary, dot
size can be increased by increasing the pre-heat pulse
width P1 beyond Pa (μ sec) so that the ejection amount

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surface of each heater reaches during the normal mode is no higher than 560°C.

Assuming that if the anti-cavitation film which constitutes the top layer of each heater is not corroded through the thermochemical reaction between the anti-cavitation film and the chelating agent or the like contained in ink, the length of the service life of a heater based ink jet head is determined only by the cavitation which occurs when a bubble generated by a heater collapses and disappears, a heater based ink jet head can generate a bubble 5×10^8 - 3×10^9 times before its service life expires. The present invention makes it possible for an exothermic resistant layer to generate a bubble as many times as the number of times given above, even if chelating agent or the like is contained in ink, assuring that a heater based ink jet head remains reliable for a long period.

The ink used in the present invention may contain coloring material, water-soluble organic solvent, water and/or the like, as desired. The coloring material may be water-soluble or not. The water-soluble coloring material may be water-soluble anionic dye, direct dye, acid dye, reactive dye or another water-soluble dye. Particularly, auriferous dye comprising TaN or cobalt has been limitedly used in the recording head using the thermal energy because

The ink used with the present invention may contain water-soluble organic solvent as desired. By using the following water-soluble organic solvent, the dissolubility of the components constituting the ink may be improved, and the viscosity may be easily adjusted. Such water-soluble organic solvents include monovalent alcohols such as methanol, ethanol or isopropyl alcohol; ketone or ketone alcohols such as acetone or diacetonealcoholic; ethers such as tetrahydrofuran, dioxane; oxyethylene or oxypropylene addition polymers such as diethylene glycol, triethyleneglycol, tetraethyleneglycol, dipropyleneglycol, tripropyleneglycol, polyethylene glycol or polypropylene glycol; alkyleneglycols having alkylene group containing 2-6 carbon atoms such as ethylene glycol, propylene glycol, trimethylene glycol, butylene glycol or hexylene glycol; triols such as 1,2,6-hexane triol; thiodiglycol; glyceline; lower alkyl ethers of polyatomic alcohol such as ethyleneglycolmonomethyl (or ethyl) ether, diethyleneglycolmonomethyl (or ethyl) ether or

5 sulfolane, N-methyl-2-pyrrolidone, 2-pyrrolidone, 1,3-
dimethyl-2-imidazolidinone.

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5 aminotrimethylenephosphonic (ATMP), or the like and
the salt thereof. The carboxylic acid type of chelate
agent includes citric acid or the like and salt
thereof. The aminocarboxylic acid type chelate agent
includes ethylenediamine 4 acetate (EDTA),
10 hydroxyethylenediamine 3 acetate (HEDTA),
glycoletherdiamine 4 acetate (GEDTA), nitro 3 acetate
(NTA), hydroxyimino 2 acetate (HIDA),
hydroxyethylglycin (DHEG), diethylenetriamine 5
acetate (DTPA), triethylenetriamine 6 acetate (TTHA)
15 or the like and salt thereof. From the standpoint of
coordinating ability, the phosphate type and the
aminocarboxylic acid type are preferable to the
carboxylic acid type.

Figure 6 shows an example of an ink jet recording apparatus equipped with a recording head in accordance with the present invention. In the drawing, a referential numeral 61 stands for a blade as a wiping member, which is supported by a blade supporting member in the form of a cantilever; it is attached to the supporting member by one of its edges. The blade 61 is placed at a position next to the

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20 While the recording head 65 returns to the
home position after the completion of a given
recording operation, the blade 61 is protruding into
the moving path of the recording head, although the
cap 62 is kept out of the moving path of the recording
25 head 65. Therefore, the ejection orifice equipped
surface of the recording head is wiped. In order to
cap the recording head 65, that is, in order to come

When the recording head 65 moves to the recording start position from the home position, the cap 62 and blade 61 are at the same positions as they are during the wiping of the recording head. Therefore, the ejection orifice equipped surface of the recording head 65 is wiped also during this movement. The above described returning of the recording head to its home position occurs not only immediately after the completion of a given recording operation, or for the ejection recovery operation, but also occurs with predetermined intervals during which the recording head moves to the next recording point across its recording range, and also during this movement of the recording head to the home position adjacent to the recording range of the recording head, the aforementioned wiping of the recording head occurs.

Figure 7 shows an ink cartridge which contains the ink to be supplied to a recording head through an ink supplying member, for example, a tube. In Figure 7, a referential numeral 40 stands for an ink storage portion, for example, an ink pouch, which

holds the ink to be supplied to a recording head. The end of the ink pouch 40 is provided with a rubber plug 42. The ink within the ink pouch 40 is supplied to a recording head by inserting a needle (unillustrated) into the ink pouch 40 through this plug 402. A referential numeral 44 stands for an absorbent member which catches and absorbs the waste ink. As for the ink storage portion, a pouch, in which the surface which comes into contact with ink is formed of polyolefine, in particular, polyethylene, is desirable for the present invention. The selection of recording heads and ink cartridges to be used with ink jet recording apparatuses in accordance with the present invention do not need to be limited to those described above, which are independent from each other. In other words, recording heads integral with an ink cartridge are also usable with the ink jet recording apparatuses in accordance with the present invention, with desirable results.

(Recording Unit)

Referring to Figure 8, a referential numeral 70 stands for a recording unit, which is structured so that an ink storage portion, for example, an ink absorbent member, is stored therein, and the ink within the ink absorbent member is ejected in the form of an ink droplet from the head portion 71 equipped with a plurality of orifices. As to the material for

the ink absorbent member, polyurethane is desirable for the present invention. A referential numeral 72 stands for an air vent for allowing the internal space of the recording unit 70 to become connected to the atmosphere. This recording unit 70 can be used in the place of the recording head illustrated in Figure 4, and is removably mountable on the carriage 66.

(Ink Selection)

The present invention is compatible with inks of any color, for example, yellow, magenta, cyan, red, green, blue, or black ink. These inks may be individually used for image formation, or may be used in a combination of two or more inks of different color, for the formation of a color image. Further, two or more inks which are the same in color but different in coloring material may be used in combination to form an image superior in gradation. When forming an image using two or more inks different in color or inks different in coloring material, a recording apparatus such as the one illustrated in Figure 9, in which four recording heads are aligned on the carriage, may be employed. In Figure 9, referential numerals 86, 87, 88, and 89 stand for recording heads for ejecting yellow, magenta, cyan, and black inks, correspondingly. Each of these recording heads disposed within the recording apparatus ejects ink in response to recording signals.

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10 [Embodiments]

Figure 11 is a sectional view of the base plate of the ink jet head in this embodiment. The recording head in this embodiment was produced by bonding a piece of glass plate with grooves for forming ink paths to the ink jet base plate. The ink jet base plate comprised a plurality of film layers: a 0.2 μm thick anti-cavitation layer 10 formed of Ta; a 0.2 μm thick protective layer 11 formed of silicon nitride; an insulative layer 8; an aluminum electrode layer comprising electrodes 3 and 4; an exothermic

resistant layer 7 formed of TaN or the like; a heat storage layer 6, and a supporting layer 20 formed of alumina or the like superior in heat radiation, which were listed in order from the side which makes contact with ink. As for the temperature at the interface between the anti-cavitation film 10 and the ink, the surface of the anti-cavitation film, which came into contact with ink, was measured using a Thermo Viewer (product of Nippon Avionix Co., Ltd.) while a heat generating element was driven with no ink on the surface of the heat generating element. This is due to the fact that a state in which the surface temperature of the protective film is at its highest level is also a state in which a bubble is being formed on the protective film surface, and therefore, the surface temperature of the protective film in this state can be approximated by measuring the surface temperature of the protective film with no ink on the protective film surface.

When a driving voltage of 25 V, which was one and half times the threshold voltage necessary to cause ink to boil, and had a pulse width of 2.0 μ sec and a frequency of 6 kHz, was applied to the heat generating head shown in Figure 11, ink boiled desirably, and the highest temperature the protective film surface reached was 545°C.

On the other hand, the resistance value $R(T)$

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Ink 1 was formulated by the following method. After the following ingredients (the ingredients listed below) were mixed, and were stirred no less

than two hours, the mixture was adjusted to 6 in pH using 10% water solution of sodium hydroxide. Then, the mixture was filtered with a membrane film with a pore diameter of 0.2 μm , obtaining ink 1.

| | | |
|---|------------------|-------------|
| 5 | C.1. direct blue | 3 wt. % |
| | Diethyleneglycol | 10 wt. % |
| | Thiodiglycol | 10 wt. % |
| | Citric acid | 0.35 wt. % |
| | Water | 76.65 wt. % |

10 The thus obtained ink 1 was ejected 6×10^8 times from the aforementioned recording head structured so that the amount of ink ejected from each orifice per ejection became 50 pico-liter, in each of the tests which were different in the driving
15 condition in terms of the highest temperature reached through the aforementioned simulation. During these tests, precipitation of burnt ink ingredients, consistency in ejection amount, and corrosion of the anti-cavitation film were examined. The results are
20 given in Table 1.

As to the state of the burnt deposit, each recording head was disassembled after 6×10^8 times of ink ejection, and the anti-cavitation film surface which had made contact with ink was visually examined
25 by an optical microscope.

As to the consistency of ejection amount, an average amount of ink ejected per nozzle after the

5 G: no less than 90% compared to the initial
amount

N: no more than 80% compared to the initial
10 amount

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below the anti-cavitation layer, were detected. Thus, the ratio of the remaining anti-cavitation film (survival rate) could be measured by comparing the strength of the signals from the constituent elements in each layer prior to the aforementioned times of ink ejection, with those thereafter.

<Table 1>

| | Exp. | Max. temp. | Burnt deposit | Ejection stability | Dis-connection | Survival rate |
|----|------|------------|-----------------------|--------------------|----------------|----------------|
| 10 | 1 | 541 (°C) | substantially nothing | G | No | 100 (%) |
| | 2 | 556 | " | G | No | 100 |
| 15 | 3 | 560 | " | G | No | 100 |
| | 4 | 570 | " | F | No | 85 |
| | 5 | 591 | " | F | No | 32 |
| | 6 | 607 | " | F | *1 | non-detectable |
| 20 | 7 | 623 (°C) | " | F | *2 | non-detectable |

*1: Occurred at 3.3×10^8 ejections

*2: Occurred at 6.7×10^8 ejections

25 G: Good

F: Fair

Among these test data, the first to third embodiments of the present invention correspond to the first to third test data one for one.

20 Regarding the burnt deposit, none was seen in
any of these tests. It was thought that the chelating
reagent having been added to ink was responsible for
this.

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precipitation of burnt ink ingredients and corrosion of anti-cavitation film could be controlled, so that ink could be consistently ejected.

(Tests 4 - 10)

5 Inks 2 - 8 were formulated in the following manner. After the following ingredients (the ingredients listed below) were mixed, and were stirred no less than two hours, and the mixtures were adjusted to predetermined pH levels, using 10% water solution
10 of sodium hydroxide. Then, the mixtures were filtered with a membrane film with a pore diameter of 0.2 μ m, obtaining inks 2 - 8.

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[illegible]

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| | | | | |
|---|--------------------------------|----------------|----------------------------|---|
| 8 | C.I Direct Blue 86 (2.5) | EDTA (0.01) | Diethylene- glycol (10) | 7 |
| | | | Water (87.49) | |

5 Each of the thus obtained inks was ejected
6x10⁸ times from the aforementioned recording head
which was provided with a 0.2 µm thick anti-cavitation
film formed of Ta and a 0.5 µm thick protective film
formed of silicon nitride, and which was structured so
10 that the amount of ink ejected from each orifice per
ejection became 50 pico-liter, while keeping the
temperature at the interface between the anti-
cavitation film surface and the ink no more than
541°C. Thereafter, the recording heads were measured
15 with respect to precipitation of burnt ink
ingredients, consistency in ejection amount, and
corrosion of the anti-cavitation film as in the first
test. The results are given in Table 3.

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<Table 3>

70360

| | | Ink | Burnt deposit | Ejection stability | Survival rate |
|----|---------|-----|---------------|--------------------|---------------|
| 5 | Emb. 4 | 2 | No | G | 100 % |
| | Emb. 5 | 3 | No | G | 100 % |
| | Emb. 6 | 4 | No | G | 100 % |
| | Emb. 7 | 5 | No | G | 100 % |
| | Emb. 8 | 6 | No | G | 100 % |
| 10 | Emb. 9 | 7 | No | G | 100 % |
| | Emb. 10 | 8 | No | G | 100 % |

G: Good

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As is evident from Table 3, whichever ink was used, neither the precipitation of burnt ink ingredients nor the corrosion of protective film was seen. Further, even when inks formed by eliminating chelating reagent from the ingredients for the inks 2, 3, and 8 were used, neither precipitation of burnt ink ingredients nor the corrosion of the protective film was seen.

On the other hand, when the above described inks 2 - 8 were ejected 6×10^8 times while keeping the aforementioned interface temperature no higher than 607°C, the thinning of the anti-cavitation film had progressed far enough to suggest the possible breakage of the heat generating head, in the cases of all inks.

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When inks formed by eliminating chelating reagent from the ingredients for the inks 2, 3, and 8 were used, the corrosion of the protective film was not seen, but in the cases of some inks, the precipitation of burnt ink ingredients was seen on the surface of the protective film on the heat generating element.

From the above observation, it is evident that when ink contains chelating reagent, the precipitation of burnt ingredients, and the corrosion of the anti-cavitation film can be better controlled to consistently eject ink, by keeping the temperature of the interface between the surface of the anti-cavitation film and ink no higher than 560°C.

Further, it is evident that even when ink does not contain chelating reagent, the precipitation of burnt ingredients and the corrosion of the anti-cavitation film can be controlled to consistently eject ink, by keeping the temperature of the interface between the surface of the anti-cavitation film and ink no higher than 560°C.

Further, when ink was ejected from the heat generating heads with an anti-cavitation film formed of amorphous alloy containing Ta, more specifically, Ta₁₈Fe₅₇Ni₈Cr₁₇, in the same manner as in tests 4 - 9, the ratio of the remaining anti-cavitation film did not drop at all even when the temperature at the

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In other words, it became evident that the precipitation of burnt ingredients and the corrosion

(Tests 11 - 14)

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Gly: Glycerine

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Material for anti-cavitation film 16-1

B1: Ta (2000 Å)

5 Material for protective film 16-2

C2: SiO₂ (5000 Å)

C3: SiC (5000 Å)

Material for heat generating member 18

D2: TaSiN (100 Å)

D3: TaAl (500 Å)

Driving conditions

heater size: 25 μm x 100 μm

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15      voltage applied: 20 [V] (constant)
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The highest temperature level which the aforementioned interface temperature reached was adjusted by varying the width of the applied pulse within a range of 1.0 - 8.0 (μ sec).

20 In other words, the highest temperature level
which the heater surface temperature reaches can be
obtained by solving Equation (4) given above, using
the values of the above conditions as inputs.

Under various combinations of the above given
25 conditions, the length of heater durability was
measured. The results are given in the following
table.

Incidentally, the heat storage layer (SiO₂) was 1.7 μ m thick, and the silicon substrate was 625 μ m.

| | | | | | |
|----|----------------------|---------|---------|---------|---------|
| 5 | | Exp. 11 | Exp. 12 | Exp. 13 | Exp. 14 |
| | Composi- tion | A | B | C | D |
| | Anti-cav.- film | B1 | B1 | B2 | B2 |
| 10 | Protection layer | C1 | C1 | C2 | C3 |
| | HTR | D1 | D2 | D2 | D3 |
| | DRIVING | * | * | * | * |
| 15 | MAX ≤ 560 °C | E | E | E | E |
| | 600 °C | B | B | B | B |
| | 700 °C | N | N | N | N |
| 20 | | | | | |

*: Constant except for pulse width

E: No change in HTR after 1.0×10^9 pulses

B: HTR break around 1.0×10^8 - 2.0×10^8 pulses

N: HTR break less than 1.0×10^8 pulses.

25 These tests proved that the present invention was effective even when chelating material was not in the ink. Further, it is evident from the above

5 (Printing Tests)

Figure 12 is a schematic drawing of a recording head and shows the general structure of the head. The recording head comprises: a plurality of heat generating heads 1103, wires 1104, ink path walls 1105, which are formed in layers on a substrate 1102, in the form of film, through semiconductor manufacturing processes such as etching depositing, and sputtering; and a top plate 1106. Ink 1112 is supplied into a common ink chamber 1108 of the recording head 1101, through an ink supply tube 1107 from an unillustrated ink storage chamber. A referential numeral 1109 stands for an ink supply tube connector. After being supplied into the common ink chamber 1108, the ink 1112 is drawn into the ink paths 1110 by capillary force, and is stably retained there as the ink in each ink path 1110 forms a meniscus at the opening, that is, orifice, of the outermost side

Figure 13 is an external view of an ink jet recording apparatus to which the present invention is applicable. This ink jet recording apparatus comprises a carriage HC, the pin (unillustrated) of which fits in the spiral groove 5005 of the lead screw 5004 rotated through driving force transmission gears 5011 and 5009 which rotate forward or in reverse as a driver motor 5013 rotates forward or in reverse. Thus, as the motor 5013 rotates forward or in reverse, the carriage HC is shuttled in the direction of an arrow mark. A referential numeral 5002 stands for a paper pressing plate, which keeps paper pressed upon a platen 5000 across the entire shuttling range of the carriage HC. Referential numerals 5007 and 5008 stand for two sections of a photocoupler which constitutes a home position detecting means for reversing the

rotational direction of the driver motor 5013; the presence of the lever 5006 of the carriage HC in the gap of the photocoupler is detected. A referential numeral 5016 stands for a member for supporting a capping member 5022 for capping the front surface of the recording head, and a referential numeral 5015 stands for a suctioning means for suctioning the substance within the cap in order to restore the performance of the recording head by suctioning the substance within the recording head through the opening 5023 of the cap. A referential numeral 5017 stands for a cleaning blade, and a referential numeral 5019 stands for a member which enables this blade 5019 to move frontward or rearward. The cleaning blade 5017 and this member for moving the blade 5017 are supported by the supporting plate 5018 of the apparatus main assembly. As to blade configuration, it does not need to be the one in this embodiment; any known cleaning blade may be employed, which is obvious. A referential numeral 5012 stands for a lever which triggers the suctioning operation for restoring the recording head performance, and moves as a cam 5020 engaged with the carriage HC moves; its movement is controlled as the driving force from the driver motor is controlled through a driving force transmitting means comprising a clutch and the like.

This ink jet recording apparatus is

However, there is no restriction regarding the

While the invention has been described with
15 reference to the structures disclosed herein, it is
not confined to the details set forth and this
application is intended to cover such modifications or
changes as may come within the purposes of the
improvements or the scope of the following claims.

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